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INFORMATION CIRCULAR

FLOTATION PROCESSES FOR CLEANING FINE COAL

This paper presents the results of work done under a cooperative agreement between the Northwest Experiment Station, of the United States Bureau of Mines, and the University of Washington, Seattle, Wash.

BY

H. F. YANCEY AND J. A. TAYLOR

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FLOTATION PROCESSES FOR CLEANING FINE COAL[1]

By H. F. Yancey[2] and J. A. Taylor[3]

CONTENTS

Page

Introduction 1
Froth-flotation process 2
  Principle of the process 3
  Early investigations 3
  British plants 6
  Froth-flotation of Indian coals 12
  In France and Belgium 13
  Dutch State mines 14
  In Germany 15
  In the United States and Canada 19
  Elmore vacuum process 23
  Some recent comments 24
Trent process 25
  Experimental investigation and principle of the process 25
  Commercial application 27
Comparison of the froth-flotation and Trent processes 27
Summary 28
Patents pertaining to coal flotation 30

INTRODUCTION

In this information circular is presented a summary of the more important articles that have appeared in the literature pertaining to the experimental work and to the commercial operation of the froth-flotation and Trent processes as applied to the cleaning of fine coal.

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The chief utility of these processes from the standpoint of present washery practice lies in the treatment of the fine coal normally present in the feed and of that produced by degradation during the washing operation. Such treatment may be applied most advantageously to the sludge and slime or to the fine coal removed from the feed before treatment. The coal subjected to these processes must be of fine size: for the Trent process through 65 mesh or finer, and for the froth-flotation process through 1/10 inch; therefore, these processes can not compete with present washing machines, except where the coal is originally fine or where exceptionally fine crushing is required to break the coal and refuse apart. Crushed middlings would fall in this class. Application may be made where the fines in a coal are high in ash or where a high-ash sludge results from the disintegration of clay during wet washing.

FROTH-FLOTATION PROCESS

The importance of froth flotation in Europe as a means of cleaning coal is shown by the tonnage treated. As early as 1925 about a million tons of coal were treated by this process.[4] Table 1 gives the amounts treated in the various European countries for the year 1925.

Table 1.- Coal flotation in Europe for the year 1925, recorded by Berthelot

	Tons (metric)
England	275,000
Germany	260,000
Spain	200,000
Holland	100,000
Belgium	80,000
Total	915,000

In the boom year of 1927, 932,036 tons of coal were treated by froth flotation in Great Britain. Since that time, the tonnage treated has declined. Table 2 shows recent coal cleaning figures for Great Britain. The total amount of coal that was cleaned since 1927 has increased steadily, while the coal cleaned by froth flotation decreased until 1930; in that year, the amount of coal cleaned by flotation was almost twice the amount for 1929, which seems to indicate a comeback for the process in the British Isles.

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[4] Berthelot, C., Washing of Coal by Flotation: Chim. et Ind., Special numbe May, 1927, pp. 334-353.

Table 2.- Quantity of salable coal cleaned in Great Britain, 1927-1930 (long tons)[1]

Method	1927	1928	1929	1930
Wet washed	49,053,761	57,363,146	65,944,925	66,285,326
Dry cleaned	1,454,291	2,773,885	5,323,194	6,305,438
Froth flotation.	932,036	189,057	63,077	123,882
Total	51,440,088	60,326,088	71,333,196	72,714,646

1/ Annual reports of the Secretary for Mines, Great Britain.

Principle of the Process

The froth-flotation process has been used successfully for ore concentraion for years. Applied to coal, the process, briefly described, involves the gitation of raw coal (all sizes up to 1/10 inch) with three to ten times its eight of water and a small quantity of suitable reagents (0.5 to 2.0 pounds er ton of raw coal). The reagent with air and water forms bubbles that electively attach themselves to the coal particles. The coal particles are uoyed up and float at the surface, where they may be removed, while most of he refuse material is wetted and remains behind.

Early Investigations

Some of the earliest investigative work on coal flotation of which the esults have been published was conducted by Bacon and Hamor[5] at the Mellon nstitute of Industrial Research, Pittsburgh, Pa. These investigators found hat the process could be used successfully for cleaning fine coal and preicted an important rôle for the process in the future. They discovered that crushing rather than a rubbing or rolling action was to be desired whenever t was necessary to reduce the size of the raw coal to be treated.

As a result of a series of studies of the froth-flotation process made n 1920-1922 by the Bureau of Mines at its Northwest Experiment Station, eattle, Wash., in cooperation with the University of Washington, and reported y Ralston and Yamada,[6] the following conclusions were reached:

1. Tests on a bony coking coal from the Wilkeson mine, at Wilkeson, Wash., have shown that the cleanest coal can be floated first, the bony coal next, and the ash last by ordinary froth flotation.

Bacon, R. F., and Hamor, W. A., Problems in the Utilization of Fuels: Jour. Soc. Chem. Ind., vol. 38, 1919, p. 163.

Ralston, O. C., and Yamada, G., Froth-Flotation Tests of Bituminous Coking Coal: Chem. and Met. Eng., vol. 26, 1922, pp. 1081-1086.
Ralston, O. C., and Wickmann, A. P., The Froth Flotation of Coal: Chem. and Met. Eng., vol. 26, 1922, pp. 500-503.

2. Very thin oils or soluble-frothing agents work best.

3. The fine sizes of coal float the most easily, and the coal in the very fine slime will float to some extent without the use of any flotation oil whatever.

4. Owing to the tendency of fine sizes to float so easily, they are probably "overoiled" and produce dirty concentrate when enough oil is added to float the coarser sizes. Screen analyses of the flotation concentrate show increasing percentages of ash in the finer sizes.

5. To take due advantage of the above facts it is necessary to use a flow sheet in which roughing treatment is followed by cleaning of both concentrate and tailing from the roughing cell, discarding as tailing the material which will not float in any of the re-treating cells. Re-treatment of middling with original feed is not desirable except for the middling obtained in cleaning the rough concentrate.

6. By this method of treatment a clean concentrate can be obtained, the bony portion of the coal forms a middling which may have a market value, and the tailing is too low in coal to be of any value.

Early British investigators[7] describe the operation of a small 8-cell froth-flotation unit that operated successfully at the Skinningrove Iron Co. in England. Starting with raw coking coal having an ash content of 10 to 16 per cent, three products were produced; a high-grade coking coal containing 3 to 4 per cent ash, a steam coal containing 10 to 20 per cent ash, and a refuse product containing 70 to 80 per cent ash content. The coking coal when carbonized gave a super product, a porous but strong coke very economical to use in a blast furnace. According to these authors, the cost of running this flotation unit was practically the same as that for a jig-washing process. It was also predicted that the flotation process would be applicable only when the original coal is fine or when crushing is part of the normal treatment - that is, for coking, gas making, briquetting, coal-dust firing, colloidal fuel, and other similar uses. British investigators claim that the facility with which the various grades of coal are separated is the most striking feature of the process.

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[7] Bury, E., Broadbridge, W., and Hutchinson, A., Froth Flotation as Applied to the Washing of Industrial Coal: Trans. Inst. Min. Eng., vol. 60, 1920-21, pp. 243-253.
Bury, A. F., and Bicknell, A., Purification of Coal by Froth Flotation: Coll. Guard., vol. 121, 1921, p. 337.

A description of an early experimental flotation plant and results ob-
ined at Aberman, England, under a joint agreement between Minerals
paration (Ltd.) and the Powell-Duffryn Co., gives the flow sheet used for
eating a variety of raw materials.[8] Runs were made with fines from run-of-
ne coking coal, steam-coal waste, and washery silt. The equipment of this
perimental plant consisted of a crushing unit, a vibrating screen, a flota-
on machine, and an Oliver continuous-vacuum filter, with the necessary con-
ying machinery. The feed, crushed to pass 6 mesh, was passed by a chute to
small bin at the head of the flotation plant. A 9-box flotation machine was
ed. The feed was introduced with a suitable amount of water into the No. 1
itation box by a screw conveyor. Because the presence of shale slime im-
ded the action of the Oliver filter and increased the ash content of the
covered coal, the froth produced in the first five boxes was re-treated in
e last four. The flotation reagents were generally added in the first box.
a rule, 1 to 1-1/2 pounds of cresylic acid was required for each ton of
w feed. A by-product gas-scrubbing effluent was used as the frothing agent,
iminating most of the cost of reagents. The clean coal fell over the lip of
e frothing boxes into the tank of the Oliver filter. It was picked up by the
um and dewatered to about 10 per cent moisture, discharged onto a belt con-
yor, and loaded into trucks. The waste material passed out of the machine
d was conveyed to the waste dump by a launder. Water from the filter could
reused, but that containing the refuse required clarification. The raw
ste treated contained 50.4 per cent of ash and the recovered coal 13.1 per
nt of ash. The yield of recovered coal was 37 per cent. The ash in the re-
vered coal could be reduced to 7.3 or 9.4 per cent if the yield were reduced
17 or 27 per cent, respectively.

Jones[9] has given a thorough discussion and presented the results of tests
the froth flotation of coal and the problems encountered. He points out
t small particles float more readily than large particles, so that a cer-
n amount of overlapping is bound to occur, but this interferes to a limited
ot practical) extent when several products are made. Trouble with pyrite go-
g with coal is admitted. Fusain (charcoal) may be removed, if present in
leterious amounts, by adding a protective colloid such as starch or glue to
e flotation pulp. Jones recommends the treatment of minus 1/2 or 1/4 inch
ed in the flotation machine. Only the clean fine coal of flotation size
oats. The tailing is passed over a screen with 1/12-inch openings and the
arse coal is recovered by tabling; fine screening of the feed is thereby
iminated.

In addition to the usual methods of dewatering, such as gravity drainage
th admixture of coarse coal and the use of continuous filters, Jones gives
e method, adapted from the briquetting process, which is novel. Water is dis-
aced from the coal surfaces by oil, due to preferential wetting. One to two
r cent of tar or tar oil (basis dry coal) is added and the mixture of floated
al, tabled coal, and water (usually 50 per cent water) is heated to 200° F.
live steam. The coal flocculates and is separated from the water on a coco-
t draining belt. It may be further dewatered by passing through a briquet
ess or by other pressure or suction methods. In 1925 the process was employed
a large scale in the north of England and was giving satisfactory results.

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ones, F. B., The Froth Flotation of Coal: Proc. South Wales Inst. Eng., vol. 37, 1921, p. 331; Abstract in Coll. Guard., vol. 122, 1921, p. 1002.

ones, F. B., The Froth Flotation of Coal: Jour. Chem. Met. and Min. Soc. South Africa, vol. 26, 1925, pp. 125-138.

British Plants

After the successful work of Bury, Broadbridge, and Hutchinson in Great Britain, many plants were erected both in England and on the continent. Some of the flotation plants that began successful operation in Great Britain are as follows: The Powell-Duffryn Co. in the Alverdare Valley; the Skinningrove Iron Co. in Wales; the Ashington Coal Co. in Durham; and the Oughterside Colliery in Cumberland.

The froth-flotation plant with a capacity of 25 tons per hour for the preparation of coking coal from raw screenings passing 1-1/2-inch round-hole screen, in operation at the Oughterside colliery, Cumberland, England,[10] was described in 1924. The cost of crushing the coal to flotation size (1/10 inch) was found to be too high, so that it was crushed only to 1/4 inch, and a Plat-O table is used to recover the coal which is too coarse to be floated from the flotation refuse. The feed was screened at 1/4 inch with a Hummer vibrating screen and fed to the first box of the machine, which consisted of two mixing boxes and eight agitation and froth boxes. Water amounting to three and one-half times the weight of coal was added to the mixing box; and the reagents, comprising a mixture of refined cresylic acid (0.77 pound per ton of coal), the aerating agent, and petroleum-gas oil (0.37 pound per ton of coal), which gives the froth stability, were added later as required. The quality of the washed product was controlled by the amount of cresylic acid and gas oil that was added as reagents. The froth contained 50 per cent of water and was dewatered to about 18 per cent by means of an 8 by 8 foot Oliver continuous filter at the rate of 26 to 28 tons per hour. The filter tank was fed by gravity from the flotation machine. Brass-wire 36-mesh cloth was used as a filtering medium. A continuous centrifugal drier was first installed to dewater the froth but failed entirely on account of the high proportion of fine material present. The discards from the eighth cell were put onto a 20-mesh jigging screen 6 feet long by 3 feet wide. Monel metal screens were preferred to steel screens because of the rapid corrosion of steel. The undersize from the 20-mesh screen was discarded as waste while the oversize was sprayed before leaving the screen and discharged onto a Plat-O coal-washing table which had a capacity of 10 tons per hour. The amount of water required on the table was 2-1/2 times the weight of the coal treated. The coal from the table was divided into three products; a coking coal, a firing coal, and a refuse product. The coking coal from the table was then intimately mixed with the flotation concentrate and sent to the coke plant.

Table 3 gives a comprehensive set of results showing the distribution of the froth products for the first seven cells of the flotation machine at this plant. In addition to the results shown in Table 3, the authors state that a reduction of the phosphorus content of the coal from 0.040 to 0.0067 per cent took place in the flotation machine. The total froth had an average ash content of 5.3 per cent. The ash and sulphur contents, as well as the average size of the coal particle in the froth, increased very noticeably from the first to the last cells.

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[10] Scoular, J. G., and Dunglinson, B., The Washing of Fine Coal by the Froth Flotation and Concentrating-Table Processes at Oughterside Colliery, Cumberland: Trans. Inst. Min. Eng., vol. 67, 1924, pp. 374-379. Abstracted in Coll. Guard., vol. 127, 1924, pp. 1061 and 1122; Gas World, vol. 80, 1924, coking section, pp. 53-57; Min. Mag., vol. 30, 1924, p. 379.

Table 3.- Samples from froth boxes taken simultaneously, according to Scoular and Dunglinson, per cent

Box No.	Ash	Sulphur	On 1/10 inch	Dry screening 1/					Separation in 1.6 specific gravity					
									Float			Sink		
				1/10-inch to 10 mesh	10 to 20	20 to 60	60 to 100	Through 100	Weight	Ash	Sulphur	Weight	Ash	Sulphur
1	3.02	1.27	-	-	3.0	33.7	18.7	44.6	98.6	2.33	1.05	1.4	51.2	9.27
2	3.16	1.35	-	-	3.9	37.6	17.0	41.5	98.5	2.38	1.20	1.5	54.5	11.30
3	3.26	1.30	-	-	12.2	48.0	13.9	25.9	98.2	2.33	1.11	1.8	54.3	11.67
4	3.73	1.37	-	0.7	20.7	46.0	10.6	22.0	97.9	2.64	1.15	2.1	55.1	11.40
5	4.73	1.59	-	3.1	42.4	35.5	5.2	13.8	97.0	3.19	1.25	3.0	54.7	12.72
6	6.02	1.78	1.4	7.5	51.7	27.0	3.1	9.3	95.4	3.52	1.31	4.6	57.8	11.54
7	7.15	2.12	1.7	11.9	5.54	20.9	3.2	6.9	94.4	4.00	1.25	5.6	60.2	16.75

1/ Cement manufacturers' standard of England sieve scale.
Openings in inches: 10 mesh = 0.0754; 20 mesh = 0.0332; 60 mesh = 0.0114; 100 mesh = 0.0065; 200 mesh = 0.0023.

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Average results for the operation of this plant for a month are shown in Table 4.

Table 4.- Average results of froth-flotation plant at Cumberland, England, according to Scoular and Dunglinson, per cent

Product	Ash	Float on 1.6 specific gravity		Sink in 1.6 specific gravity	
		Weight	Ash	Weight	Ash
Raw coal	21.58	75.4	4.77	24.6	73.10
Flotation coal, filter	5.30	97.0	3.90	3.0	50.70
Coking coal from table	5.00	100.0	5.00	-	-
Boiler coal from table	14.66	90.5	10.72	9.5	51.52
Refuse from 20-mesh screen.	75.80	-	-	100.0	75.80
Refuse from table	72.78	3.5	22.64	96.5	74.61

On the basis of moisture-free coal the average yields are as follows: 70.4 per cent of coking coal containing 5.25 per cent of ash, 7 per cent of boiler coal containing 14.66 per cent of ash, and 22.6 per cent of refuse containing 75.5 per cent of ash. As the coking coal recovered by flotation contained 5.3 per cent of ash and that from the table 5 per cent of ash and the mixture of the two contained 5.25 per cent of ash, it may be calculated that 83.3 per cent of the coking coal was furnished by flotation and 16.7 per cent by the table. It is pointed out that a slight disadvantage of the flotation process is the tendency of pyrite to float if the aeration is too strong and that this is likely to happen in the last few boxes of the machine when extra reagent is added to lift the coal of poorer quality. It was found that the froth from the last two or three boxes, when screened at 40 mesh, gave an undersize that was mainly pyrite.

The capital and operating costs of this plant for the year 1924 were as follows:

Capital cost of main items:	Pounds sterling	U. S. dollars[11]
Minerals Separation flotation machine	3,500	17,033
Oliver filter, including all pumps, air compressor, etc.	1,500	7,300
Hum-mer screen, with generator	600	2,920
Total capital cost	5,600	27,233

Operating costs:

(1) Crushing: The cost of crushing is practically the same as if the coal were washed in a jig washery and crushed after washing for coking.

(2) Screening, washing, drying, and disposal of products.

	Per ton, pence	Per ton, cents
(a) Labor: Three men and one youth with a charge hand who works in conjunction with the laboratory	2.58	5.24
(b) Reagents:		
Cresylic acid, 0.77 pound	1.77	3.59
Gas oil, 0.37 pound	.23	.47
(c) Repairs, renewals, stores	.71	1.44
Total operating cost	5.29	10.74

The royalty charged by the Mineral Separation Co. amounted to 3½ pence or 7.1 cents per ton. Forty-five horsepower was required to drive the flotation machine; this was higher than would be necessary if all the feed under the 1/10-inch size were treated. Only about half the quantity of cresylic acid given would be needed at this size. The filter required 45 hp. and the concentrating table, screens, etc., 4 hp. The water required for the whole plant was 200 gallons a minute.

The coke manufactured was an excellent blast-furnace fuel and commanded a premium on the market, besides being salable when the demand is slack. The average analysis showed 91.8 per cent of fixed carbon and 7.7 per cent of ash. The coke was harder than that formerly produced, and less breeze was made. Koppers standard regenerative-type ovens were used. The by-product yield of ammonium sulphate and tar increased while the production of benzol decreased.

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[11] Exchange at par value.

Another interesting British plant that has operated successfully with a Baum washer has been described by Guider.[12] In this plant, operated by the Clifton & Kersley Coal Co. (Ltd.), a dry 2½-inch slack was screened on a ½-inch screen, the oversize being treated in a separate jig washer from the undersize material. The Baum washer treating the minus ½-inch coal, although removing most of the refuse material, permitted the finely suspended dirt to go over with the washed coal. The dirty suspension, as well as the fine coal, was removed from the minus ½-inch washed coal on a 0.5-mm., wedge-wire, fixed screen, set at an angle of 30° from the horizontal. The 2½ to ½ inch washed coal from the other washer was dewatered and sized in a trommel screen. The sludge that accumulated from both the coarse and the fine dewatering screens went to a sump, from which point it was pumped to a settling tank. The sludge from this settling tank, containing 25.6 per cent solids, was the feed for the flotation machine. A sizing test and float-and-sink analysis of the sludge is shown in Table 5.

The flotation machine, a 6-cell Minerals Separation type, had a capacity of 25 tons per hour. The froth produced by the machine was scraped off by paddle wheels and fell into a trough that delivered it directly to the minus ½-inch jig-washed coal contained in a draining-band bucket conveyor. The coal was then ready for either storage or shipment.

Table 6 shows a size and a float-and-sink analysis of the froth and tailing products.

The material over 1/10 inch was taken out of the tailing by means of a wedge-wire screen and returned to the fine-coal jig. The froth product, while considerably improved in quality, still contained some fine clay, probably due to the fact that a considerable amount of suspended clay comes over with the wet coal from the flotation machine.

Table 5.- Screen and specific-gravity analyses of the feed at a British flotation plant, according to Guider

Size, inches	Weight, per cent	Float in 1.35 specific gravity, per cent	1.35 to 1.60 specific gravity, per cent	Sink in 1.60 specific gravity, per cent
Plus 1/4	1.8	1.6	0.2	-
1/4 to 1/10 .	8.2	6.6	1.2	0.4
1/10 to 1/20.	8.7	6.7	1.3	.7
Minus 1/20 ..	81.3	46.3	18.7	16.3
Total ..	100.0	61.2	21.2	17.4

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[12] Guider, W., Froth Flotation Applied to a Baum Washer: Jour. Soc. Chem. Ind., Trans., vol. 46, 1927, pp. 238-242.

Table 6.- Screen and specific-gravity analyses of the flotation products at a British plant, according to Guider

FROTH

Size, inches	Weight, per cent	Float in 1.35 specific gravity, per cent	1.35 to 1.60 specific gravity, per cent	Sink in 1.60 specific gravity, per cent
lus 1/20 ..	5.0	4.5	0.5	-
/20 to 1/60	38.0	33.5	4.0	0.5
inus 1/60..	57.0	37.0	15.0	5.0
Total..	100.0	75.0	19.8	5.5

TAILING

Size, inches	Weight, per cent	Float in 1.35 specific gravity, per cent	1.35 to 1.60 specific gravity, per cent	Sink in 1.60 specific gravity, per cent
lus 1/10 ..	1.6	1.0	0.3	0.3
/10 to 1/20	4.2	1.4	1.4	1.4
inus 1/20...	94.2	3.4	7.9	82.9
Total..	100.0	5.8	9.6	84.6

The reagent utilized at this plant was a rather crude quality of creosote il. After trying several types of reagents, it was found that a cheap grade f creosote oil (1.7 pound per ton) gave better and more economical results han other more expensive reagents such as cresylic acid. The cost of perating the flotation plant per ton of coal was as follows:

	Pence	Cents[12a]
Interest on capital (5 per cent)	5.60	11.38
Depreciation (7 per cent)	7.84	15.90
Royalty	4.00	8.12
Power	3.84	7.80
Wages (one man)	1.85	3.76
Reagents	1.50	3.04
Total	24.63	50.00

The increased cost per ton of total slack (through ½ inch) was stated to e 6.1 pence or 12.4 cents as result of the installation of the flotation lant; but the ash content of the washed slack was reduced from 10.0 per cent o 6.0 per cent by the change. The high ash content of the jig product was ue to the fact that the raw coal contained a large amount of shale that asily disintegrated to a finely divided clay that went over with the jig-ashed coal because the Baum washer is unable to separate such fine dirt from ine coal. Froth-flotation removed most of the clay suspension without a large loss of fine coal. The loss of coal in the flotation tailing amounted o only 0.1 per cent of the total slack (through ½ inch) fed to the washer.

[12a] Exchange at par value.

Guider considers the major disadvantage of the flotation system to be the fact that the coal froth retains such a large amount of moisture. Water remains with the fine coal so tenaciously that even after mixing with the coarser through ½-inch coal and draining for a period of 30 minutes, the mixture has a moisture content of 18 per cent.

Froth-Flotation of Indian Coals

Randall[13] has investigated the possibility of cleaning Indian coals by the froth-flotation process. A large proportion of the mineral matter contained with Indian coals is very intimately mixed with the coal substance and for this reason cleaning is difficult by ordinary washing methods. Randall states that "tests at various meshes show that to set free the constituent bands of Indian coals it is necessary to crush the coals to about 1/20 inch." For the reason just cited, all of the flotation tests were made with coal crushed to pass a 1/20-inch screen.

Typical results obtained by Randall in a laboratory flotation machine on face samples considered to be representative of run-of-mine coal are shown in Table 7.

Randall's work also showed the ash contents at higher yields of coal. At yields of 80 per cent, the froth products increase 3 or 4 per cent over the values shown for 60 per cent yields; the refuse products likewise show an increase of from 10 to 20 per cent in ash contents. Nevertheless, the ash contents of the refuse products remain rather low even at comparatively high yields of froth concentrates, due no doubt to the bony nature of the coals that were being treated.

Table 7.- Froth flotation tests of Indian coking coals, according to Randall

Description of coal	Raw coal ash, per cent	Washed coal		Refuse	
		Weight, per cent	Ash, per cent	Weight, per cent	Ash, per cent
Jharia No. 18 seam	16.3	60	9.4	40	26.7
Jharia No. 13 seam	18.0	60	10.5	40	29.3
Jharia No. 16 seam	22.4	60	11.8	40	38.3
Bokaro, Kargali seam	22.3	60	15.8	40	32.1
Bokaro, Kargali seam[1]	20.6	60	10.5	40	35.8
Barakar, Ramnagar seam	13.6	60	7.6	40	22.6

1/ One-half-inch slack.

The bright coal was more friable and had a much lower ash content than the dull coal. The slack formed in mining was therefore of a higher grade than the run-of-mine coal. For this reason Randall advised the use of preferential crushing for the run-of-mine coal. The minus ½-inch slack should then be used as the raw material for making coke while the plus ½-inch materi should be used for steam firing.

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[13] Randall, W., Froth Flotation of Indian Coals: Rec. Geol. Survey India, vol. 56, part 3, 1925, pp. 220-249.

In France and Belgium

About 180,000 tons of coal were cleaned by froth flotation in France in 1926. Since that time many other plants have been built both in France and in other parts of Europe, and the yearly production of floated coal therefore has increased accordingly.

At the Noeux colliery in France a plant of 1,000 metric tons (1 metric ton is 2,204.6 pounds) capacity per 24-hour day has been built for treatment of a heap of washery refuse.[14] The material was dug by shovel and sent to the flotation plant by aerial tram. Here it was passed first through a 20-mm. vibrating screen of the Hum-mer type (capacity 60 tons per hour). The oversize, which contained more than 75 per cent of ash, was discarded. The remainder, which already contained 8 per cent of moisture, was pulverized wet in a Jeffrey swing-hammer pulverizer (capacity 500 tons per day; another of 700 tons capacity was being installed). It was then screened wet through a 2-mm. sieve (which will be replaced by a 2.5-mm. sieve), the larger material (over 74 per cent of ash) being again rejected. The fine material passes with five times its weight of water to four Minerals Separation, standard 5-compartment, froth-flotation washers, each of 250 tons daily capacity (two in use when the article was written). The froth was dewatered from 60 to 15 per cent of moisture in two Oliver continuous, vacuum filters, each of 20 square meters surface. The waste waters were treated in Dorr thickeners; the dirt was discarded in the form of a thick mud with 50 per cent moisture. The feed to the flotation cells contained 61.16 per cent ash. The yield of recovered coal was 23.3 per cent, and its ash content was 20.28 per cent. The process appears to be successful, but the exact cost per ton treated has not been stated.

Berthelot[15] gives the flotation results for two plants installed by the Minerals Separation Co. in Belgium. Tables 8 and 9 show the results at these two plants which are located at Charleroi and at Bonnier.

Berthelot gives the cost figure for treating a ton of fine raw coal as about 3 francs or 58 cents. He says that the installation should pay for itself within a year.

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[14] Chataignon, M., La flotation en son application au terril de Noeux: Rev. Ind. Min., vol. 4, 1924, p. 361; abstract in Fuel and Science and Practice, vol. 3, 1924, p. 453.
Pirlot, F., Application of Flotation to the Treatment of Coal Schists of the Slack of Noeux: Rev. universelle mines, vol. 7, part 4, 1924, pp. 97-107.

[15] See footnote 4.

Table 8.- Flotation results at Charleroi, according to Berthelot 1/

	Per cent
Ash content of the raw slimes	30
Ash content of the washed slimes	8
Ash content of the refuse	70
Yield of washed slimes	65
Yield of refuse	35
Moisture after dewatering	16 to 18

1/ Reagents: Mixture of creosote and wood-tar oils, 800 to 900 grams (1.8 to 2 lbs.) per ton of raw coal.

Table 9.- Flotation results at the Bonnier coal mine, according to Berthelot 1/

	Per cent
Ash content of 0 to 2½ mm. of raw coal	30
Ash content of 0 to 2½ mm. of washed coal	7.5
Ash content of middling product	20
Ash content of middling and concentrate together	9
Ash content of refuse	76
Yield of combined middling and concentrate	68
Yield of refuse	32

1/ Reagents: 500 grams (1.1 lbs.) gas oil and 100 to 150 grams (0.22 to 0.33 lbs.) petroleum oil per ton of raw coal.

Dutch State Mines

The froth-flotation process invented by Kleinbentinck,[16] the chief engineer of the Dutch State mines, is used at many of the Dutch mines. At the Emma mine, six Kleinbentinck units having a total capacity of from 12 to 15 tons of sludge per hour, treated a raw sludge with 25 per cent ash. From the first unit, a froth containing 8.5 per cent ash was obtained, and from the second, a froth containing 7.0 per cent ash. The combined remainder from the two units had an ash content of from 36 to 40 per cent. Upon re-treating this remainder, a product containing 10 to 12 per cent ash was obtained, leaving a refuse with an ash content of 57 per cent.

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[16] Chapman, W. R., and Mott, R. A., The Cleaning of Coal: Chapman & Hall (Ltd.), London, 1928, p. 431.
Stavorinus, D., The Purification of Coal by Foam Flotation: Het Gas, vol. 45, 1925, pp. 266-270.

According to the inventor, the Kleinbentinck process requires 2.7 hp. per ton of raw coal treated. The reagent used by the Dutch State mines was a mixture of one part of napthalene oil and two parts of anthracene oil, both oils being by-products of tar distillation. One and three-quarters pounds of reagent were required per ton of sludge.

The Kleinbentinck process, besides being used by the Dutch State mines, has found application in other parts of Europe. At the Aniche mine, France, three sets of Kleinbentinck units, each set having a capacity of 15 tons of sludge per hour, were installed. The sets were so arranged that the tailing from the first set was rewashed in the second set and the tailing from the second set was rewashed in the third set. In this manner three froth products were obtained with ash contents of 7.5, 11.0, and 18 per cent. Exclusive of the power required for pumping, 4 hp. per ton was required for the throughput of 15 tons per hour. Reagent consumption was 1.6 to 1.8 pounds per ton of sludge treated. In this case a tar-oil distillate boiling between 230° and 270° C. was used as the reagent.

In Germany

Schäfer[17] describes the introduction of the froth-flotation process into Germany for the cleaning of bituminous coal sludges as a utilitarian move. Before the introduction of the flotation process as much of the high-ash and high-sulphur sludges as could possible be used were added directly to the coking coal. The remainder that could not be utilized satisfactorily was sent to waste. The froth-flotation process made it possible to use a much greater percentage of the sludges without materially increasing the ash and sulphur contents of the coke. As an example, Schäfer cites an improvement in the cleaning of a coking coal from the Waldenburg district. By the usual washing process, a 56 per cent yield of material 0.5 to 10 millimeters in ize with an ash content of 5.5 per cent was obtained. After the flotation rocess was introduced as an aid to the washer, the yield was increased to 8.2 per cent and the ash content remained the same as before. In addition, t was shown that by saving some of the slightly higher ash coal, a yield of 8 per cent could be obtained with a total ash content of 6.5 per cent. Another similar example was cited for a high-volatile coal from the Rhine-Westphalian district.

The first commercial plant using the froth-flotation process for cleaning oal in Germany was built at the Mont Cenis coal mine. Wüster[18] has described he Gröndal and France flotation process which is being used at the Mont Cenis mine for the treatment of coal sludge. Two grades of coal were produced, one for coking and the other for steaming. Five tons of sludge were produced for each 125 to 150 tons of coal washed. By using 470 to 480 grams (about 1 pound) of oil per ton, the coking coal recovered contained about 7.5 per cent of ash, the steam coal about 14.5 of ash, and the refuse 75.8 per cent of ash. The yield was 2.27 tons per 5-ton unit, and the ratio of coking coal to steam coal was approximately 2 to 1. The sulphur content decreased from 2.6 per cent in the sludge feed to 0.77 per cent in the coking coal; the refuse contained 4.3 per cent of sulphur.

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[17] Schäfer, O., Treatment of Coal Slimes by Froth-Flotation Process: Stahl u. Eisen, vol. 45, 1925, pp. 1-7 and 44-51.

Schranz, H., Coal and Ore-Flotation Methods: Krupp Monatsh., vol. 6, 1925, pp. 57-64.

[18] Wüster, R., Die Schwimmaufbereitung von Kohle nach dem Verfahren von Gröndall und Franz auf der Zeche Mont Cenis: Glückauf, Bd. 60, 1924, pp. 19-23; Chem. Abs., vol. 18, 1924, p. 1188.

The general results obtained at five German flotation plants, as recorded by Schäfer, are shown in Table 10. The first three plants had 10-cell, Minerals Separation type flotation machines, while the fourth plant had an 8-cell unit of the same type. The plant at the Mont Cenis mine has already been described as of the Gröndal design.

Table 11 shows the cost figures for the first four plants. The cost figures for the Mont Cenis flotation plant are not given.

Table 10.- Results at German coal flotation plants, recorded by Schäfer

Description	Ash in raw sludge, per cent	Ash in concentrate, per cent	Ash in refuse, per cent	Yield of concentrate, per cent	Capacity, tons per hour
Zwickau, Saxony	35-40	8-9	70-75	50-55	12
Mölke, Silesia 1/	20-23	8-9	1/30-35	45-50	35
Gelsenkirchen, Westphalia	9-10	5-6	75-80	92-94	15
Altenwald, Saar	22-25	7-8	65-75	70-72	10
Mont Cenis, Westphalia	25-30	7.5	75	2/About 50	5

1/ In this case the separation was intentionally made to yield a concentrate with an 8 to 9 per cent ash content and a middling product with 30 to 35 per cent ash content.

2/ In addition a 24 per cent yield of a middling product containing 14.5 per cent ash was obtained.

Table 11.- Operating costs of German flotation plants per ton of raw coal treated, recorded by Schäfer 1/

	Power		Reagents		Wages		Repairs		Total	
Description	Marks	Cents	Marks	Cents	Marks	Cents	Marks	Cents	Marks	Cents
Zwickau, Saxony	0.13	3.1	0.10	2.4	0.05	1.2	0.06	1.4	0.34	8.1
Mölke, Silesia.	.03	.7	.10	2.4	.02	.5	.02	.5	.17	4.1
Gelsenkirchen, Westphalia ...	.08	1.9	.10	2.4	.04	.9	.05	1.2	.27	6.4
Altenwald, Saar	.13	3.1	.10	2.4	.06	1.4	.07	1.7	.36	8.6

1/ Exchange at par value.

Schäfer also gives the cost of removing the excess water from the concentrate containing 50 to 70 per cent moisture by the use of a pressure-type filter press that removes the water down to 18 per cent. The cost is about 0.8 mark or 19 cents per ton. In this case the cost of removing the excess water from the fine coal is more than twice that for the removal of the dirt alone.

Lucke[19] describes the introduction of the froth flotation system for cleaning coal as a distinct move toward economy. He states that at a bituminous coal washery in the Ruhr district an increase of 3 per cent in the total production of washed coal was brought about by the use of flotation; at gas-coal washeries 10 per cent increase, at Saar and Wurm coal washeries 12 to 15 per cent increase, and at Saxon and Silesia coal washeries a total increase of 20 per cent or more in yield was recorded. In eastern Germany in the Saar and Wurm districts the flotation of coal sludges has been unusually successful, and for this reason the process has a very firm foothold in these districts.

Lucke describes experimental work conducted by the Central European Flotation Preparation A. G. at the research plant of the Humboldt Machine Construction Co. The Humboldt Co., located at Köln-Kalk, constructs flotation machines under the patents of Minerals Separation (Ltd.). The experimental work was carried out with a representative sample of a fine high-volatile coal from a coal washery operating at a mine in the Ruhr district. The washery had a daily capacity of 1,300 tons. Table 12 shows screen and ash analyses of the raw coal and the products of the washery which did not use flotation.

The results indicate that the washing operation is rather effective down to the 0.5-mm. size, but below that size no improvement is shown. For this reason the raw fine coal was screened on a 0.5-mm. screen, and only the material which passed the screen was used for flotation testing. Table 13 shows flotation results on the minus 0.5-mm. coal.

Table 12.- Sieve and ash analyses of raw and washed fine coal from the Ruhr district

	Raw fine coal		Washed fine coal		Fine refuse	
Grain size, millimeters	Weight, per cent	Ash, per cent	Weight, per cent	Ash, per cent	Weight, per cent	Ash, per cent
2 to 8	78.0	12.1	54.8	4.0	44.0	69.3
1 to 2			21.2	6.2	34.7	66.7
0.5 to 1			8.9	9.7	7.4	69.2
0.3 to 0.5	4.4	14.7	3.1	16.3	3.6	64.6
0 to 0.3	17.6	22.6	12.0	26.1	10.3	60.5
0 to 8	100.0	14.0	100.0	8.0	100.0	67.4

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[19] Lucke, M., Higher Yields of Fine Coal by the Use of Flotation: Ztschr. Verein deutcher Ing., vol. 73, 1929, pp. 1345-1349.
Pieters, H. A. J., The Flotation of Coal Sludges: Brenstoff Chem., vol. 12, 1931, pp. 325-327.

Table 13.- Flotation results on minus 0.5 mm. fine coal from the Ruhr district, according to Lucke

Product	Weight, per cent	Ash, per cent
Minus 0.5 mm. raw fine coal	100.0	21.0
Flotation concentrate	77.3	6.8
Refuse	22.7	69.3

These data show that the flotation process effectively cleans the material that is relatively unimproved by the washing process used at this plant. For the washing plant in question it was calculated that the total yield of fine coal would be increased by 11.5 per cent, or, on a daily tonnage basis, about 130 tons of coal or more would be saved.

An economical study of the losses that were occurring at the washing plant was also made. By estimating the value of the untreated sludge at 3 marks or 68 cents per ton, and the value of the coal that could be saved by flotation at 14.5 marks or $3.35 per ton, the value of the two products for a year would amount to 117,000 marks or about $27,870 for the untreated sludge and 652,500 marks or about $155,400 for the floated coal. The operating cost of the flotation process for a year, judging from the practice in the district, was estimated at 23,100 marks or about $5,500 (0.51 marks or 12 cents per ton of concentrate produced). The yearly loss that was estimated to be occurring at this plant was therefore 512,400 marks or about $122,000. Lucke states that in Germany the average flotation plant, including the cost for dewatering apparatu will pay for itself in 8 to 12 months of operation.

This author describes a horizontal-type centrifugal dryer, which he calls a rapid dewaterer, as giving very satisfactory results with coal sludges. The dewaterer, simply described, consists of a horizontal, trommel-type, revolving screen into which the coal is delivered. Centrifugal force causes the water to pass through the screen. A spiral scraper within the dewatering screen keeps the fine coal continually moving through the apparatus. The water passing through the dewaterer is sent back to the flotation circuit for reuse. The dewaterer works especially well when the floated coal is first mixed with a larger size of fine washed coal prior to the dewatering. A mixture of 10 per cent of floated coal and 90 per cent of fine coal was reduced in moisture content in this apparatus to 8.8 per cent. This product was then dry enough for immediate coking.

As a general rule, the addition of floated coal to fine washed coal prior to coking increases the yield and the strength of the high-temperature coke. Table 14 gives results showing the effect of floated coal upon the strength of coke. The method of testing was not given.

The normal amount of floated coal that was available for addition to the fine washed coal at the plant where the tests, shown in Table 14, were made was 12 to 15 per cent.

Table 14.- Effect of floated coal upon the strength of coke, recorded by Lucke

Description	Strength, kilograms, per square centimeter
Coke from washed fine coal	124
Coke from washed fine coal plus 5 per cent floated coal ..	138
Coke from washed fine coal plus 10 per cent floated coal ..	150
Coke from washed fine coal plus 15 per cent floated coal ..	163
Coke from floated coal	220

Another German author states that fine coal (0 to 0.5 mm. size) can be cleaned of ash and sulphur very satisfactorily by flotation.[20] The product, however, will contain about 25 per cent water, after filtration, and most of the fusain present in the original coal. Experiments are described which show the feasibility of mixing this product with coarser coal intended for coke manufacture. Coals running 24 to 32 per cent volatile matter are used in the tests. Volatile matter in floated fines ran 2 to 4 per cent lower than that of the coarse coal, mainly because of concentration of fusain in the former. This decreased the coking power in some cases but improved it in others. Bräuer thinks the addition of fines tends to favor cementation of the whole carbonizing mass into a dense hard coke. In one case the addition of 20 per cent of 0 to 0.3 mm. floated coal to the charge increased the stability from 78.3 to 80.5 per cent and decreased the porosity from 41 to 39.4 per cent. Practical methods for mixing the fine coal with the rest of the charge are discussed. The resultant mixture should not contain over 9.5 per cent water, and mixing should be thorough, since segregation of the fines will often cause weak spots in the resultant coke. Good practice is to add the fines from the filter (containing 20 to 25 per cent water) in a thin stream to the rest of the coal while it is being forwarded to the charging wagons on a belt conveyor.

In the United States and Canada

In the United States the use of the froth-flotation process for cleaning coal has not spread as rapidly as it has in Europe. In fact only a few flotation plants have been installed for this purpose. A small washery constructed in 1926 at Snoqualmie, Wash., treated washery sludge by froth flotation with satisfactory results; but this plant was operated only at irregular intervals because of other unfavorable conditions. Two washeries on Vancouver Island, British Columbia, have used the process in the past, one at Nanaimo[21] for treating slack, sludge, and picking-table refuse, and the other at Cassidy[22] for recovering coal from a high-ash washery sludge.

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[20] Bräuer, O., Utilization of Floated Coal in Coke Ovens: Glückauf, vol. 67, 1931, pp. 657-662. Abstracted by J. D. Davis, Chem. Abs., vol. 25, 1931, p. 5749.

An experimental laboratory study of the problems encountered in the froth flotation of coal, particularly with reference to the finding of reagents suitable for the depression of pyrite is in progress at the U. S. Bureau of Mines, Northwest Experiment Station at Seattle, Wash., in cooperation with the College of Mines, University of Washington. The compilation of the literature on froth flotation reported in this Information Circular has been used as a basis for the experimental study. These studies have not been completed and have not yet appeared in published form, but the most effective and economical depressants of pyrite found so far in the work are ferrous and ferric sulphates when used in the hydrogen ion concentration range between 4.5 to 6.9. After ferric sulphate has once come into contact with pyrite in a coal pulp in this range it affords depressive action even if the pulp is then carried to the alkaline side of neutrality by the addition of calcium hydroxide or other alkaline reagents.

In general, depressing reagents for pyrite are greatly hampered in their action in the flotation of coal by two factors. These factors are, first, the mechanical entrapment of pyrite particles by the enormous number of coal particles constantly going upward into the froth, and, second, the amount of fine-sized particles of pyrite that remain suspended in the water that accompanies the coal froths. Such detrimental action can be minimized by dilution of the pulp prior to flotation or by the recleaning of the coal froths.

The Pittsburgh Coal Co., Pittsburgh, Pa., has made intensive laboratory and plant investigations of the suitability of the froth-flotation process for cleaning coal sludge. Their results have not been published, but through the courtesy of J. B. Morrow, preparation manager, the following summary of their experimental work prepared by Zimmerman, Younkins, and Crawford of the company' preparation department technical staff, has been made available:

This outline of the experimental work on the froth flotation of coal conducted by the Pittsburgh Coal Co. summarizes the laboratory testing of certain coals and the investigation of various reagents as to their applicability in coal flotation.

Laboratory procedures were governed according to the usual accepted methods, paying close attention to pulp density, agitation, conditioning, reagents and step oiling, water supply, etc. In order to obtain check results, tests were run according to a standard set of procedures.

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[21] Coal Age, Flotation Plant Will Treat Slack, Sludge, and Picking-Table Refuse: Vol. 21, 1922, pp. 365-366.

[22] Peterson, P. E., Cleaning Vancouver Island Coals by Froth Flotation Process: Coal Age, vol. 21, 1921, pp. 243-244.

Although many coals and cleaning plant products were tested by flotation, the most important material was the Dorr thickener underflow products from the company's three cleaning plants, Champion 1, Champion 4, and Champion 5. This product was uncleaned by the regular coal-washing system used in cleaning the coarser sizes of coal and was approximately of the right size for flotation without any further sizing. Thickener underflow varies in the percentages of sizes present and in ash and sulphur contents according to the plant. Champion 1 has the highest ash and sulphur content and percentage of plus 48-mesh coal. Champion 4 and Champion 5 have lower-ash thickener underflows and comparatively little sulphur. Fifty to sixty per cent of the sulphur is organic and sulphate sulphur and as such can not be removed by flotation. The rest is in the form of pyrite and marcasite.

Particles in thickener underflows larger than 48 mesh were found to interfere with the flotation of the finer sizes, particularly when the finer sizes were extremely high in ash and the plus 48-mesh material low in ash, as is the case at all three plants. Much of the minus 200-mesh material is in the form of slimes. There is also a high percentage of colloids in the thickener-overflow water used in flotation. Both slimes and colloids interfered with flotation of thickener underflow. The most effective methods for dealing with these impurities were by means of greater pulp dilution, recleaning of concentrates, and the use of acid circuits. Sodium silicate showed a tendency to disperse the slimes but affected recovery and caused pyrite to float.

Acid circuits were found to give better-grade concentrates, although maximum recovery was reached at a slightly alkaline (7.0 to 7.5 pH) condition. At higher pH concentrations the recovery and grade dropped appreciably, particularly after 8.5.

The amount of soluble salts and alkalinity of the water supply varies at each of the three plants. Champion 1 water has the lowest amount of soluble salts and only slight alkalinity. The water at Champion 4 has an alkalinity of 160 parts per million and 1,596 parts per million of soluble salts. Champion 5 is the only plant whose water supply is on the acid side, with 35 parts per million of free acid and a soluble salt content midway between that of the other two plants.

None of the plants has water which inhibits flotation. The excessive amount of soluble salts at Champion 4 caused a slight retardation to flotation of coal but the effect was not as nearly marked as is evident with excessive slimes and colloids.

Sulphur reduction was important only at the Champion 1 plant. Here a thickener underflow with 3 per cent sulphur made it essential to remove as much of sulphur as possible. Fifty per cent of the total sulphur content of the underflow product at Champion 1 is in the form of organic and sulphate sulphur. The remainder is pyrite and marcasite. The depression of pyrite-marcasite increases with increase of pH. Depressing reagents recommended for

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pyrite in coal flotation are lime and iron sulphates. Laminated particles of coal and pyrite are difficult to depress. Oxidized pyrite, however, aids in the depression of pyrite.

In the cleaning of coal by froth flotation, mechanical entrapment of impurities, including pyrite, in the froth was found to be one of the most important factors in interfering with an efficient separation since 80 to 90 per cent of the feed is floated. In order to compensate for this at least one recleaning of the concentrates is recommended.

Cresylic acid was found to be the best frothing agent for our purpose although pine oil and flotation aldol gave good grades of concentrates except with respect to sulphur content. An important factor in choosing a frothing agent was the need for a brittle froth. Pennsylvania crude oil, kerosene, solar oil, and water-gas tar were found to be satisfactory collectors in the flotation of coal.

According to Parmley,[23] the clean coal obtained by froth-flotation treatment of thickener underflow at the plants of the Pittsburgh Coal Co. is dewatered to about 21 per cent moisture by Oliver, Dorr, and Laughlin type filters. The filter cake is further dried to 3 per cent moisture by means of rotary heat dryers after mixture with the 0 to 3/8 inch size of washed coal discharged from Carpenter centrifugal dryers. The performance of the heat dryers and the size composition of the components of the feed, including the flotation coal, is shown in Table 15.

The cost of heat-drying the fine coal (0 to 3/8 inch) at this plant, which amounts to about 14 per cent of the washer feed, is given by Parmley as 7 cents per ton of dry coal. This figure represents operating costs and supplies only and does not include depreciation and overhead charges. The power and fuel required in the drying plant are given as 1.60 kw.-hr. and 15 pounds, respectively, per ton of coal dried.

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[23] Parmley, S. M., Heat Drying of Washed Coal: Trans. Am. Inst. Min. and Met. Eng., Coal Division, vol. 94, 1931, pp. 336-350.

Table 15.- Coal fed to three heat dryers, according to Parmley

	Centrifugal dryer product, 0 by 3/8 inch	Filter product	Composite feed to heat dryer	Discharge from three cyclones
Tons per hour	100 to 120	20 to 25	120 to 145	3
Moisture in feed, per cent	6.5 to 8.5	21	7.5 to 9.5	-
Moisture in discharge, per cent	--	--	3.0	1.5
Screen test, per cent weight				
On 3/8 inch round	0.0	0.0	0.0	0.0
14 mesh 1/	72.0	0.0	62.0	20.0
48 mesh	20.5	33.0	22.0	48.0
100 mesh	3.5	31.0	7.5	22.0
200 mesh	1.5	14.0	3.5	6.0
-200 mesh	2.5	22.0	5.0	4.0
	100.0	100.0	100.0	100.0

1/ Tyler standard sieves.

Elmore Vacuum Process

Chapman[24] states that one of the outstanding recent developments in the wet cleaning of coal is the introduction of the Elmore vacuum-flotation process, formerly used in ore flotation. The ordinary type of flotation machine requires a large amount of power for the violent agitation needed. The rather stable froths produced by these machines are difficult to break down and to dewater. The Elmore process, according to this author, eliminates these major disadvantages of the mechanical process by operating under a vacuum without agitation.

In the Elmore process the raw coal (under 1/8 inch) is mixed with about six times its weight of water together with a small amount of suitable reagents. The feed is then delivered into the frothing chamber through a conical barometric leg. The feed pipe gradually increases in diameter toward the frothing chamber to allow for the free expansion of the pulp caused by the low pressure in the frothing chamber. The pressure in the main body of the apparatus is 24 to 27 inches of mercury below atmospheric. The reduced pressure causes the formation of air bubbles from three general sources: First, air dissolved in the water; second, air released from the structure of the coal particle; third, air attached to the oiled-coal particles during the mixing. The general result is a floating of the coal particles upward into an overflow pipe, where they are removed, while at the same time the refuse particles are left behind and are separately removed by a pipe attached to the bottom of the vacuum chamber. The two outlet pipes (over 30 ft. in height) carry their separate products out of the flotation chamber to atmospheric pressure. The froth from the vacuum process collapses immediately upon leaving the vacuum chamber and by natural drainage the coal below 1/8-inch in size can be reduced to 12 per cent moisture in two hours. This is considered to be about half the normal amount usually retained by minus 1/8-inch coal. The power requirements for the operation of the process are very low.

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[24] Chapman, W. R., Recent Progress in Coal-Cleaning Practice in Great Britain: Proc. Third Internat. Conf. Bit. Coal, vol. 2, 1931, pp. 741-758.

Chapman does not describe a commercial plant employing the Elmore process but states that the process has been shown, on a commercial scale, to give better results than normal present practice. Table 16 shows experimental results obtained with this process.

Table 16.- Purification of fine coal in experimental vacuum flotation plant, according to Chapman 1/

Description	Ash, per cent		
	Raw coal	Clean coal	Refuse
Scotch slurry	15.4	4.2	58.5
Kent coal	8.8	3.8	56.0

1/ Chapman, W. R., and Mott, R. A., The Cleaning of Coal: Chapman and Hall (Ltd.), London, 1928, p. 436.

Some Recent Comments

As an example of the remarkable results that can be obtained by the froth-flotation process, Chapman[25] is quoted as follows: "At a colliery in the north of England coal is being cleaned by froth flotation and coked, and the cleaning is so effective that the coke is sold under guarantee with not more than 1 per cent of ash."

Berthelot[26] states: "Two large plants, the Randolf Colliery and the Dumbreck Colliery, use flotation coal for making supercoke containing only 1.5 per cent ash, which is used for the manufacture of electrodes."

Chapman further states that the use of the flotation process for cleaning coal has been held back for two main reasons: First, the ordinary type of machine requires a large amount of power for operation; second, coal froths are difficult to dewater. He claims, however, that since the process is the only positive method for cleaning coal sludges, it is again coming into prominence for cleaning coal in Great Britain. He also predicts that the recent development of the Elmore vacuum-flotation process will eliminate most of the previou difficulties encountered with the ordinary type of flotation machine.

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[25] See footnote 24.

[26] Berthelot, C., Modern Methods of Washing Coal, Especially Fine Coal: Proc Third Internat. Conf. Bit. Coal, vol. 2, 1931, p. 761.

TRENT PROCESS

Experimental Investigation and Principle of the Process

The Trent process, invented by Walter E. Trent, makes use of the selective wetting of coal by oil and of mineral matter by water. The raw fine coal (through 100 mesh or finer) is suspended in water and then mixed with oil amounting to 30 or 40 per cent of the coal. The coal particles form with the oil a pasty agglomerate that sinks to the bottom while most of the refuse material remains suspended in the water. The coal mixture may then be removed. The agglomerate, called an amalgam, retains 8 to 12 per cent moisture.

The United States Bureau of Mines has studied the effectiveness of the Trent process in reducing the ash and sulphur content of coal on a laboratory scale[27] and the results of destructive distillation of the coal-oil mixture produced by this method of treatment.[28] The study of the effectiveness of the process in reducing the ash and sulphur content of coal was conducted by Perrott and Kinney, whose report should be consulted. Table 17 following summarizes their results.

Table 17 shows that in many cases the Trent process causes a very effective separation of dirt from coal. When the amalgams are carbonized at a high temperature, exceedingly large amounts of a high-grade gas are produced and, in many instances, a firm coke product is formed even when noncoking coals are used.

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[27] Perrott, G. St. J., and Kinney, S. P., Laboratory Studies of the Trent Process: Rept. of Investigations 2263, Bureau of Mines, July, 1921, 18 pp. Reprinted in Chem. and Met. Eng., vol. 25, 1921, pp. 182-188, and Coal Age, vol. 20, 1921, pp. 132-134, 172-175. See also Haanel, B. F., Trent Process for Purifying Coal High in Ash: Canada Dept. Mines, Summary Rept. 574, 1920, pp. 43-44.

[28] Davis, J. D., Place, P. B., and Scott, G. S., Destructive Distillation of Mixtures of Oil and Coal: Rept. of Investigations 2301, Bureau of Mines, December, 1921. Reprinted in Chem. and Met. Eng., vol. 25, 1921, pp. 1131-1136.

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Davis, J. D., Distillation Gases Yielded by Trent Amalgams and Ethylene Found Therein as a Source of Alcohol: Rept. of Investigations 2415, Bureau of Mines, November, 1922.

Table 17.- Summary of results of Trent process, according to Perrott and Kinney

Kind of coal and source	Oil used, gallons per ton	Raw coal, per cent		Cleaned coal, per cent			Refuse, per cent			Agitation period, hours
		Ash	Sulphur	Weight	Ash	Sulphur	Weight	Ash	Sulphur	
Anthracite:										
Culm I	65	27.7	1.00	74.0	7.0	0.70	26.0	87.0	1.99	0.5
Culm II	65	31.4	1.63	69.0	6.5	.85	31.0	87.0	3.05	.5
Rhode Island	75	21.7	.85	82.0	6.7	.83	18.0	90.7	.95	2.0
Bituminous:										
Pittsburgh bed	80	12.5	1.27	92.0	6.0	1.34	8.0	88.0	.40	.1
Upper Freeport bed.	80	9.3	2.28	96.5	6.7	2.34	3.5	87.6	.60	2.0
Bone-coal refuse ..	80	21.7	.93	88.0	12.5	.80	12.0	88.7	2.08	1.0
Illinois	80	16.6	5.33	85.0	7.4	5.28	15.0	69.7	2.25	3.0
Indiana	80	9.9	4.38	96.4	6.3	4.27	3.6	86.2	.80	.5
Oklahoma	80	19.5	4.74	69.0	5.7	3.08	31.0	50.5	8.50	2.0
Washington	80	22.6	.49	87.5	13.6	.50	12.5	85.0	.50	.5
Brazil	60	35.6	2.47	66.0	9.4	2.32	34.0	86.0	2.71	4.0
Bituminous refuse:										
New Mexico	60	54.7	.55	45.0	22.9	.86	55.0	80.6	.29	2.0
Tennessee	50	63.5	1.64	31.0	20.6	1.48	69.0	82.7	1.65	2.0
Alabama	80	23.5	1.60	80.5	6.6	1.76	19.5	92.8	.90	1.0
Subbituminous:										
Washington	80	19.3	.48	87.0	10.0	.50	13.0	80.0	.45	3.0
Lignite:										
California 1/	80	35.1	1.77	81.5	25.7	1.56	18.5	75.9	2.30	2.0
Texas 1/	80	33.5	1.44	79.7	18.1	1.42	20.3	94.2	1.25	2.0

1/ Carbonized at 500° C.

Commercial Application

The Trent process may be said to have had only a limited commercial application. According to Davidson,[29] in January, 1925, five plants were manufacturing under Trent patents in the United States and one in France. Because of the high cost of manufacture and because of the increased competition in the market caused by other types of fuels, many of the plants have since closed. The Toledo plant, described by Davidson, in a period of eight months produced some 35,000 tons of bulk amalgam. This plant operated successfully for a period of several years. From 85 cents to $1 screenings the plant manufactured bulk amalgam at a cost of $6 per ton. The freight charges were low for the raw material but exceedingly high for the finished product. Amalgam manufactured at Toledo, Ohio, for $6 per ton, when shipped to Detroit, Mich., could be sold for no less than $11 to $13 per ton. In order to make the product more adaptable for home use many attempts have been made to put the bulk amalgam into the form of clean attractive oil-proof packages, but because of the high cost of manufacture and the failure of the public to adopt the new type of fuel, the process has not been entirely successful from a commerical standpoint.

COMPARISON OF THE FROTH-FLOTATION AND TRENT PROCESSES

A direct comparison of the froth-flotation process with the Trent process when both are applied to the Pacific Northwest coals has been made by the Bureau of Mines at Seattle, by Ralston.[30] Table 18 gives the average results obtained by the two methods when the same coal is treated. All of the coals tested were from the State of Washington and were rather high in inherent ash. Of the five coals tested, two were subbituminous, two bituminous, and one semianthracite. Ralston's work is so well summarized in the conclusions of this paper that they are quoted here in part as follows:

Table 18.- Comparison of work done by Trent and froth-flotation processes, according to Ralston,[1] per cent

aw-coal ash	Trent process				Flotation, 65 mesh	
	300 mesh		65 mesh			
	Concentrate ash	Recovery 2/	Concentrate ash	Recovery 2/	Concentrate ash	Recovery 2/
5.3	9.0	99.5	13.5	99.0	13.8	90.4
0.8	10.6	98.0	13.5	98.0	15.5	80.0
6.5	12.2	98.0	16.3	96.0	18.4	90.0
4.8	15.8	99.5	18.0	98.5	18.8	96.0
3.7	7.7	99.5	10.8	99.0	10.7	97.0

/ All figures on moisture-free basis.
/ Recovery of combustible material.

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9 Davidson, E. W., Toledo Plant Makes Trent Amalgam Better Known: Coal Age, vol. 27, 1925, pp. 139-142.
Dacy, G. H., Plastic Fuel Can be Made of Low-Grade Coal and Oil and Can be Coked Even if Noncoking Coal is Used: Coal Age, vol. 21, 1922, pp.953-956.
Kneeland, F. H., Plant in Newark Makes Briquets by Trent Process: Coal Age, vol. 26, 1924, p. 715.

0 Ralston, O. C., Comparison of Froth with Trent Process: Coal Age, vol. 22, 1922, pp. 911-914.

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1. Froth flotation and the Trent process, when applied to the cleaning of various coals ground to pass a 65-mesh sieve for the purpose of preparing a low-ash fuel, gave very similar results under conditions which were most favorable to the froth-flotation work and somewhat unfavorable to the Trent work.

2. Under these conditions the grades of concentrate made by the two processes were almost identical for all kinds of coals tested, with a slight advantage in favor of the Trent process when heavy oils were used.

3. The extractions of combustible matter are higher in the Trent process, the differences being slight for semianthracite and coking bituminous, but up to 5 or 10 per cent for the lower grades of coal.

4. The Trent process carries the bony coal into the "clean" coal product, whereas it is possible by froth flotation to carry the cleanest coal into a first concentrate and the bony coal can then be taken off in a second concentrate, which can be segregated, if desired. For this reason the froth-flotation process is the more flexible of the two.

SUMMARY

The use of the froth-flotation process has increased the yield and quality of the marketable coal products in all of the plants that have been described. The total plant yields have been increased as much as 3 to 20 per cent. In the cases where the process has been applied to the cleaning of fine coking coal, the resulting coke has been considerably improved with regard to strength, ash content, and, in many instances, sulphur content.

The reagents that have been used at the many different coal flotation installations vary to a considerable extent. Those plants that were located near a by-product coking installation generally made use of coal-tar derivatives such as creosote oil, cresylic acid, tar-oil distillates, and napthalene or anthracene oils as reagents. Other plants employed such products as gas oil, petroleum oil, and wood-tar distillates. The reagent consumption usually amounted to from 1 to 2 pounds per ton of dry raw coal.

The feed to the coal-flotation plants described usually contains 20 to 25 per cent solids. Two products, a clean coal froth and a tailing or refuse product usually are made. The coal froths from the flotation machines contain 50 to 70 per cent moisture. The tailings from the flotation plants usually contain only a small amount of good coal and therefore generally are sent to waste.

Many European flotation-plant operators consider the problem of dewatering flotation concentrates as one of the major disadvantages of the process. At the various plants many methods have been used to dewater the froths. One of the simple methods that has been used has been the pouring of the froth concentrate onto coarser coal contained in a slow-moving drainage conveyor. The moisture content of the mixture was reduced in this way to 18 per cent. The revolving-drum filter has been used to dewater coal-flotation concentrate at a number of plants. According to the literature on the subject, the method is rather expensive but more positive in its action than the simple draining method. The minus 1/10-inch froth concentrate can be dewatered by this method to 15 or 20 per cent moisture. If this material then is mixed with a considerable amount of the through ½-inch coal (1 part of froth to 10 parts of ½-inch coal), the resulting product will contain about 8 to 10 per cent moisture and is suitable for coking purposes. The centrifugal dryer has been used successfully in Germany for dewatering mixtures of coal froths with coarser coal. This process gave results somewhat similar to those obtained with the revolving-drum filter. Other methods of dewatering the froth concentrates have been tried, but, regardless of the method that has been used, it seems to be a well-recognized fact that the cost of removing the excess water from the clean coal concentrates is a large item of expense. In several cases the cost of dewatering the concentrates has equaled or exceeded the cost of the main process itself.

It is difficult to summarize the cost items at the various European plants, due to differences in the manner of presentation of cost data; positive dewatering costs may or may not be included. However, from the information available it may be estimated that the operating cost of a plant which includes cost of power, labor, reagents, repairs, and similar small items, is about 10 to 25 cents per ton. If the cost of depreciation, interest on investment, and royalty charges is included, the cost may amount to as much as 50 or 60 cents per ton of raw coal treated.

PATENTS PERTAINING TO COAL FLOTATION

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1,388,868 - Jones, F. B., and Bury, E. Froth flotation. Aug. 30, 1921.
1,418,547 - Edser, E., Sulman, H. L., and Jones, F. B. (Assignors to Minerals Separation North American Corporation.) Treatment of materials containing coal. June 6, 1922.
1,499,872 - Price, F. G. (Assignor to Minerals Separation North American Corporation). Treatment of coal. July 1, 1924.
1,539,746 - Kleinbentinck, J. W. Means for refining coal slimes or the like. May 26, 1925.
1,551,956 - Bates, L. T. Separating ash-forming constituents from coal by flotation. Sept. 1, 1925.
1,578,274 - Eldred, B. E., and Graham, R. N. Flotation separation of coal and ash or similar material. March 30, 1926.
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1,655,849 - Stenning, W. W. Concentrating coal by froth flotation. Jan. 10, 1928.
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218,012 - Minerals Separation (Ltd.). Mineral flotation separation. March 29, 1923.
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Dutch

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